Remote Observations of a Combined Dryline and Cold Frontal Event

B. B. Demoz,[1,2] D. O'C. Starr, A. R. Lare[3], K. D. Evans[2], J. Spinhirne, S. Scott, R. A. Ferrare[2]

NASA Goddard Space Flight Center, Greenbelt, MD 20771

G. Mace

Pennsylvania State University, University Park, PA 16802

1. INTRODUCTION

The occurrence of a dryline in advance of an approaching cold front is often associated with formation of severe thunderstorms over the central United States. Such conditions occur frequently in late spring when abundant low level moisture moves north from the Gulf. Understanding and thus forecasting of these severe conditions requires knowledge of the atmospheric moisture structure and the underlying dynamics shaping the boundary layer.

This study presents remotely sensed data collected during a combined dryline/cold-front passage that preceded a severe weather event. The data for this study were collected during the Atmospheric Radiation Measurement (ARM; Stokes and Schwartz, 1994) Remote Cloud Sensing (RCS) Intensive Operations Period (IOP) on April 14-15, 1994 at the Southern Great Plains Cloud and Radiation Testbed (CART). Data from satellites, the Goddard Space Flight Center (GSFC) Scanning Raman Lidar (SRL; Ferrare et al., 1995), the GSFC Micro Pulse Lidar (MPL; Spinhirne, 1993), and the 94 GHz Pennsylvania State University cloud radar (Clothiaux et al., 1995) are considered here. NWS and Oklahoma mesonet data as well as microwave radiometer measurements made at the locations are used in the interpretation of the event.

A short discussion of the synoptic conditions, the instruments, and data are presented below.

2. SYNOPTIC CONDITIONS

A cold frontal system moved from Colorado into northern Texas and Oklahoma (Fig. 1, Top) on 14 April 1994 (all times are UTC). However, much of Oklahoma and Texas were under the influence of a poleward moving airmass of high moisture content bounded on the west by a dryline (Fig. 1, Bottom). The confluence of these systems led to a line of severe thunderstorms through the central United States. Interaction between the cold front and dryline also initiated an undular bore (Smith, 1988) in the moist, nocturnal stable boundary layer over the CART site.

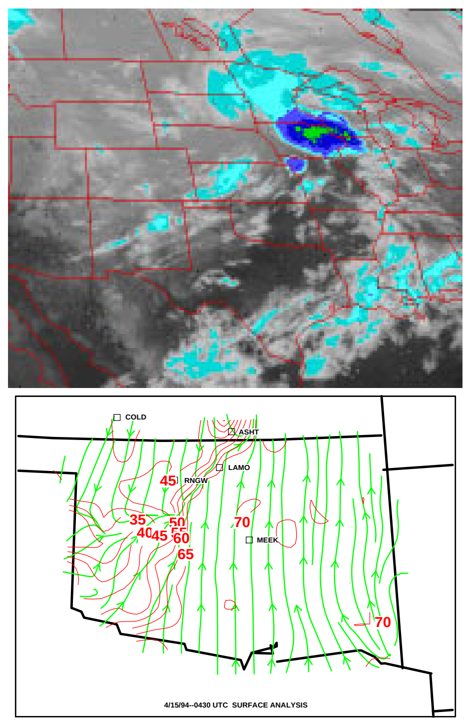

Figure 1. Top: Infrared satellite imagery at 0400 on 15 April, 1994. Cold front stretches from northeast Kansas through western Oklahoma and into Texas panhandle at this time. Bottom: Streamline and dew point temperature (^oF) analysis of surface observations from the Oklahoma Mesonet, NWS, and ARM stations on 15 April, 1994.

[1] Corresponding author: Belay B. Demoz, NASA/GSFC Code 913, Greenbelt, MD 20771
[2] Hughes STX, Lanham, MD 20771
[3] Applied Research Corp., Landover, MD 20785

3. REMOTE SENSED DATA SETS

3.1. THE MPL

The MPL is a compact, eye-safe lidar system that uses a low power and high repetition rate laser for automated, longterm cloud and aerosol profiling in the troposphere and lower stratosphere. It can detect clouds as high as the tropical tropopause (Spinhirne, 1993), unlike the standard laser ceilometers that are limited to the lowest three to four kilometers. The MPL was operated continuously at the CART site during the ARM RCS IOP. Observations on 14-15 April 1994 (Fig. 2) revealed an undulating middle level cloud layer followed by the pre-frontal low level roll clouds associated with the undulare bore at 0430 (Julian day 105.2). Though the response to aerosol is not as strong as seen from cloud particles, the MPL data does capture the lifting of the frontal surface after 0430 and the continuation of the moist layer associated with the previous mid-level cloudiness. Intersection of the features again initiated mid-level cloud formation at the end of the time period shown.

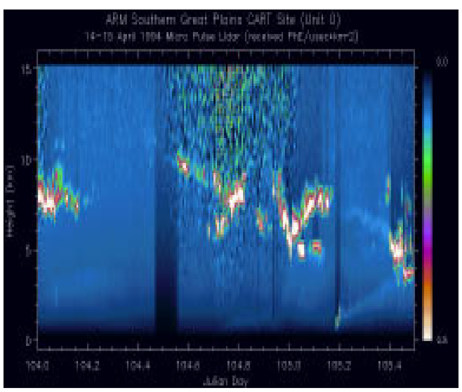

Figure 2. A signal image display of the MPL measurements for April 14-15, 1994 over the CART site. Clouds are visible as higher photo-electron counts per range bin. A higher return signal from a sinking moist surface and the cold frontal surface are also visible. Note also the difference between day-time profiles (with solar noise) and night-time measurements.

These measurements show the MPL to be an excellent tool for cloud and aerosol observations. It is superior to conventional ceilometers, that have limited range and responsivity or surface observer reports where visual estimates of cloud base height are strictly qualitative and nighttime observations are questionable.

3.2. THE 94GHz CLOUD RADAR

The Pennsylvania State University 94GHz cloud radar was designed as a compact, low-power, zenith pointing system sensitive to cloud droplets and ice crystals. It was routinely operated at the CART site to monitor the vertical structure of clouds from the surface. The data for April 14-15, 1994 revealed an impressive image (Fig. 3) of boundary layer development and clouds. Visible in good detail are the mid-tropospheric clouds detected by the MPL, the near-surface aerosol layer (visualizing the boundary layer undulations associated with the bore), the slanted top of the bore induced roll clouds, and the slope of the cold frontal surface (lower right).

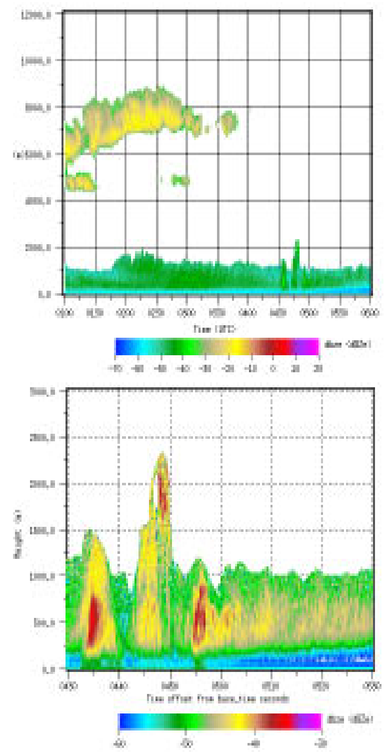

Figure 3. Image of the 94GHz measurements of April 14-15, 1994 over the CART site. Top: data showing detailed structure of mid-tropospheric clouds and the near-surface boundary layer structure during the night. Bottom: magnified view of the boundary layer undulations associated with the undular bore.

The 94GHz radar is heavly attenuated by rain and is not operated during such conditions. In addition, like most radars, it requires cloud particles or high concentrations of haze or aerosol to reveal information about fair weather atmospheric conditions.

3.3. THE SRL DATA

The SRL is a high resolution (75 m) nighttime instrument that senses water vapor mixing ratio to altitudes of more than 8 km. The capability to sense water vapor mixing ratio makes the SRL ideal in visualizing the cloud free boundary layer. The SRL data for the night of April 14-15, 1994 are given in Fig. 4. The sudden moistening of the lower boundary layer associated with the dryline, the deep undulations in moisture and roll cloud formation due to the undular bore, the moisture structure of the cold frontal surface leading to the early morning clouds (1000 UTC), and the existence of well-mixed conditions in the layer above are all visible in great detail.

The moisture content of the atmosphere is a major parameter controlling the atmospheric energetics. The detailed structure of atmospheric moisture, as captured by the SRL in this case, provides a unique characterization of the dynamic processes that are operating. It also visualizes the different airmasses involved in shaping the atmospheric structure using their moisture content. At present, the SRL is a nighttime only sensor. However, daytime operation is possible and is under development. While it provides a highly resolved water vapor and aerosol structure of the atmosphere, the SRL is highly attenuated by thick clouds.

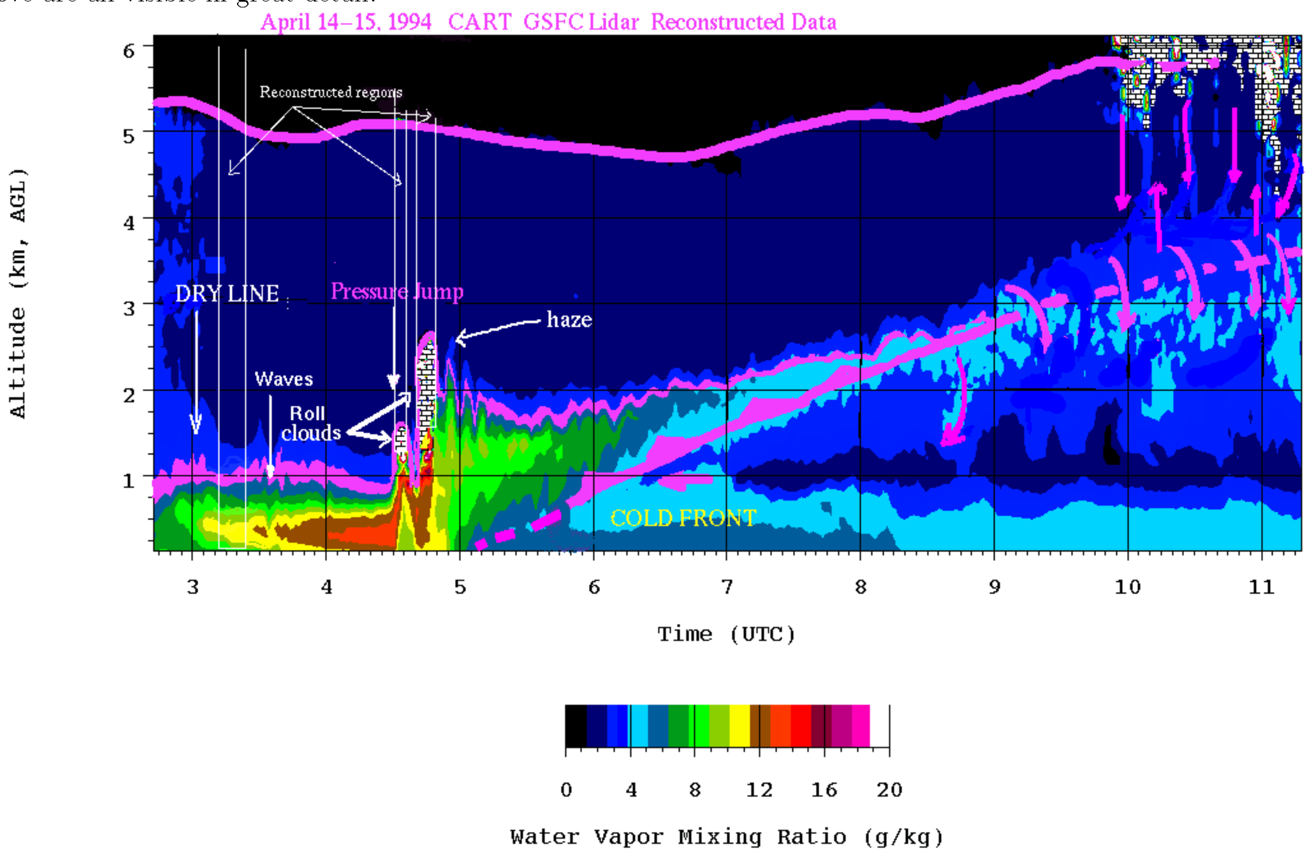

Figure 4. Reconstructed image of SRL mixing ratio ($g\ kg^{-1}$) profiles on April 14-15, 1994 during the ARM RCS IOP showing the dryline, undular bore, cold frontal surface, clouds, and the mid-tropospheric inversion. The location of the pressure jump and preceding wave activities as well as the post frontal turbulent mixing periods are indicated. Cloud boundary during the undulare bore period were determined using the 94GHZ radar and SRL cloud base estimates.

3.4. ADDITIONAL DATA

In addition to the remote sensing data presented above, a number of other data sets were also used in interpreting this case study. These include surface observations of temperature, pressure, humidity, wind speed and direction, from the Oklahoma mesonet as well as additional surface, radiosonde and tower observations from the ARM network including microwave radiometer-measured cloud liquid and precipitable water amounts (not shown here).

3.5. SUMMARY

We have documented the structure of the atmosphere during a cold frontal passage on 14-15 April 1994 that was proceeded by dryline conditions using data from various remote sensing instruments.

Satellite imagery was used to show synoptic scale cloud coverage and movement of the main systems involved; the cold air mass from the north and the warm and moist air from the south. Limitations of satellite data in identifying both cloud base and top heights were rectified by the MPL and cloud radar measurements. For example, a general decreasing trend of cloud top and base height of the undulating mid-level clouds prior to the frontal passage (visible in the MPL measurements) was not accessible from satellite pictures.

The MPL, while ideal for long term automated cloud and aerosol profiling operation, did not resolve the atmospheric structure at lower altitudes. The lack of detail at low altitudes in the MPL measurements was in turn rectified by the cloud radar and the SRL measurements. The radar revealed an abrupt lift in the depth of the boundary layer at about 0200 on 15 April 1994, an hour before the arrival of the dryline at the site according to the SRL records, indicating the occurrence of increased moisture and/or blowing dust. The western edge of the moist air mass, the dryline, arrived over the CART site at about 0300 on 15 April 1994 and was confirmed by tower measurements and mesonet data. Note that the 9 g/kg mixing ratio contour is assumed to indicate the dryline boundary following Schaefer (1986).

The SRL and the radar data sets also showed detailed structure of the atmosphere during the cold frontal passage and the bore undulations. The radar data revealed the intense undular bore downdraft and updraft better than the mixing ratio profiles of the SRL. However, the SRL mixing ratio profiles were superior in revealing the stratified atmospheric layers of different stability conditions which are important in controlling the dynamic processes. The moist layer at the bottom, the mid-tropospheric well-mixed layer and the abrupt drying aloft (above 5 km) and their modification by the approaching cold front and undular bore waves was clearly visualized by the mixing ratio profiles of the SRL.

The SRL output could also be compared to standard ground based and tower measurements of mixing ratio and humidity as well as to microwave radiometer measurements directly. SRL measurements on this day compared very well with microwave radiometer measurements of precipitable water and with humidity (mixing ratio) values measured from an instrumented tower (Ferrare et. al., 1995).

In summary, we demonstrate the technological capabilities that now exist to enable meteorologists to probe the fine scale features of atmospheric events like dryline, bore, frontal structure and fair weather stratification.

4. REFERENCES

Clothiaux, E. E., M. A. Miller, B. A. Albrecht, T. P. Ackerman, J. Verlinde, D. M. Babb, R. M. Peters, and W. J. Syrett, 1995: An evaluation of a 94 GHz radar for remote sensing of cloud properties. *J. Atmos. Oceanic. Technol.*, **12**, 201-229.

Ferrare, R. A., S. H. Melfi, D. N. Whiteman, K. D. Evans. F. J. Schmidlin and D. O'C. Starr, 1995: A comparison of water vapor measurements made by Raman Lidar and radiosondes. *J. Atmos. Oceanic Technol.*, **12**, 1177-1195.

Schaefer, J. T., 1986: The Dryline. In *Mesoscale Meteorology and Forcasting,* American Meteorological Society, Boston, 549-572.

Smith, R. K., 1988: Travelling waves and bores in the lower atmosphere: The "Morning Glory" and related phenomena. *Earth Science Rev.*, **25**, 267-290.

Spinhirne, J. D., 1993: Micro pulse lidar. *IEEE Trans*, **31**, 48-55.

Stokes, G.M. and S.E. Schwartz, 1994: The Atmospheric Radiation Measurement (ARM) Program: Programmatic background and design of the cloud and radation test bed. *Bull. Amer. Meteoro. Soc.*, **75**, 1201-1221.